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Introduction

The major sources of phosphate substances in surface waters are human wastes, synthetic detergents, certain industrial wastes, and runoff from agricultural and forest lands. The purpose of this paper is to discuss some of the factors which bring about various concentrations of phosphate substances in the runoff from rural areas (agricultural and forest land), present the results obtained in stream surveys, and estimate the contribution of phosphate from land runoff.

Phosphate in Rural Land

In 1939 H. H. Bennett, Chief of the U. S. Soil Conservation Service reported that an analysis of 389 samples of surface soils throughout the United States showed an average phosphate PO_4 content of .145 percent. (1) Phosphoric acid is formed when water having a pH below seven or on the acid side, comes in contact with phosphate rock. In 1952 W. H. Waggaman observed a phosphate content of .067 to 0.24 percent for the first nine inches of good productive soils. (2)

The use of land for growing crops has several effects on water quality, one of which is the land's contribution of nutrients to streams

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* This paper was prepared to document a study of runoff as a source of phosphate in the streams and lakes and thus make the information available for reference and publication. March 13, 1967

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and lakes. The land which is most fertile offers the highest monetary return when used to grow crops. To obtain even higher returns, fertilizers are applied to maintain or enrich the soil fertility.

The Great Lakes-Illinois River Basins Project (GLIRBP) made a study to determine the approximate quantity of phosphate in commercial fertilizers used in each subbasin of the Lake Michigan Watershed. By turning to Table I we see these present and future estimates. Figure 1 gives the location of the subbasins. Approximately 85 percent of the commercial fertilizers in this watershed are applied in the spring and the remainder in the fall. In the spring particularily, some of the fertilizer is washed off the land and carried into the lakes and streams. Dr. O. J. Attoes, College of Agriculture, University of Wisconsin, in an interview with the writer, stated his opinion that only a very small amount of phosphate applied in fertilizer would reach streams. This view is supported by the Department of Agriculture, in "Soils and Men," Yearbook of Agriculture, 1938. The book points out that about 55 pounds per year of phosphate are applied in general farming; that crops remove an average of 30 to 60 pounds a year; and therefore not much accumulation of phosphate will occur, unless crop residues and manure are saved and returned to the land.

Studies by C. N. Sawyer(3) suggested, however, that the contribution of total phosphate to surface waters by land drainage in the Madison, Wisconsin area was approximately 390 pounds of PO_4 per year per square mile of which about 75 percent could be attributed to organic origin.

TABLE I

PHOSPHATE USE
LAKE MICHIGAN WATERSHED

Subbasin Estimates [1]

Subbasin Number	Tons[2] Per Year PO_4		
	Present	1980	2020
WL-24	2,007	2,910	3,813
WL-25	6,463	9,366	12,279
WL-26A	2,315	3,358	4,399
WL-26B	2,037	2,957	3,870
WL-27A	197	288	375
WL-27B	43	64	83
WL-28A	993	1,445	1,887
WL-28B	1,692	2,455	3,218
WL-29	1,254	1,820	2,385
WL-30	10,226	14,828	19,428
WL-31	5,014	7,272	9,527
WL-32	12,644	18,334	24,024
WL-49	1,378	2,000	2,622
Totals	46,263	67,097	87,910

1/ The factors used in this projection are the result of a consultation with Messrs. William H. Heneberry and John Hastetler, Agriculture Economists, Economic Research Service, U. S. D. A. and Dr. Robert E. Lucas, Department of Soil Science, Michigan State University.

2/ Phosphate estimates are based on fertilizer usage as given in 1959, U. S. Census of Agriculture.

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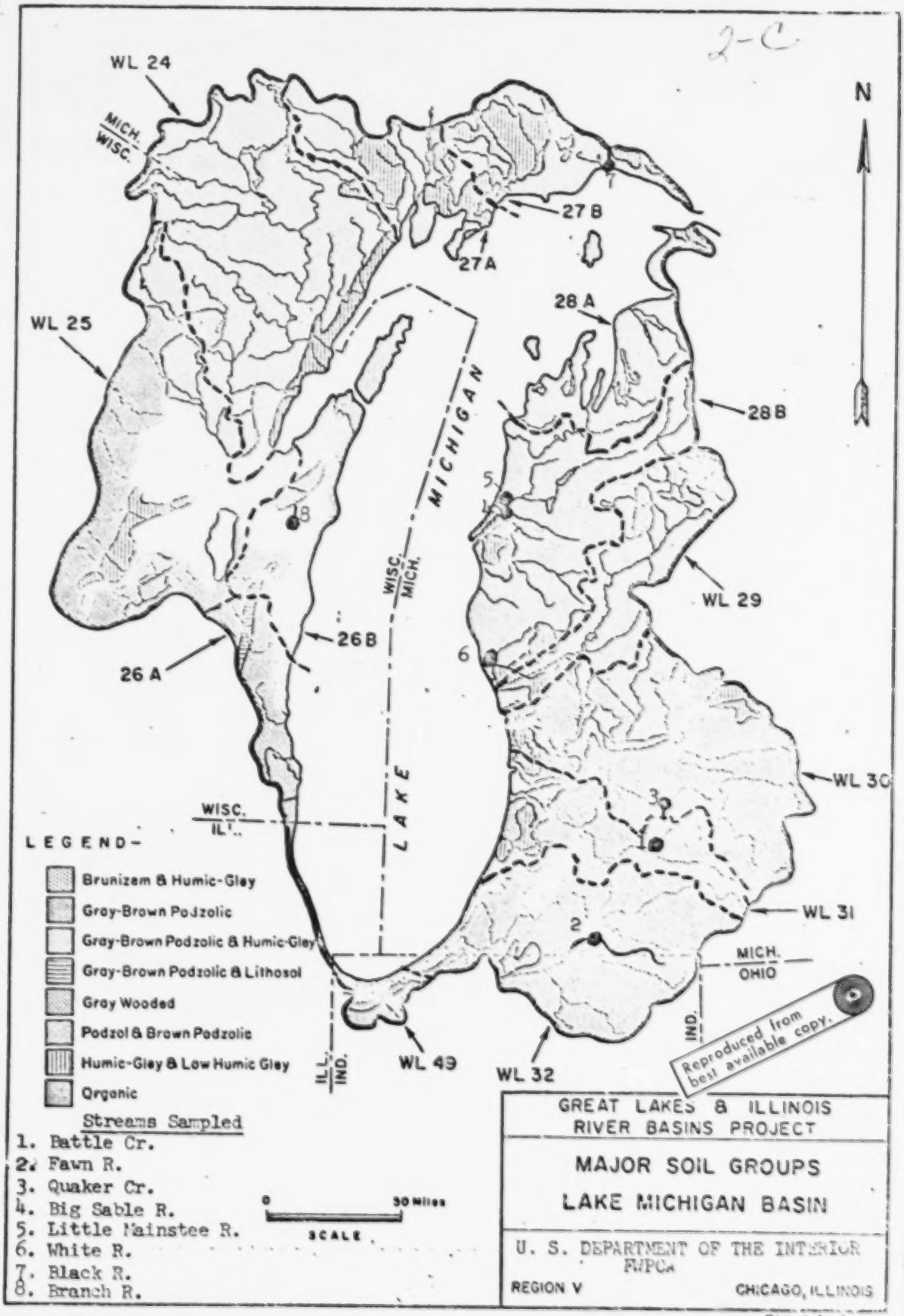

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FIGURE 2

Engebrecht and Morgan[4] reported a value of 690 pounds of phosphate per year per square mile of land area in the Kaskaskia River Basin of Illinois. If runoff occurs quickly after the start of a rain, soluble salts accumulated in the surface soil during a dry period may be washed off before infiltration carries them into the body of the soil. Percolation water contains a relative low concentration of salts. Dr. Walton shows[5] total phosphate concentrations in water from irrigated fields to be 0.3 mg/l for tile drain effluents.

Another large and growing source of phosphate is domestic animal waste. Dr. Attoes, previously cited, believes this may be a much greater contributor of nutrients to streams than is direct runoff from crop land - especially in areas having large concentrations of livestock in feedlots and barnyards. As feed is digested by livestock its constitutents are converted to highly soluble form. Average farm manure as applied to the field contains approximately 6.7 pounds of phosphate per ton of manure. (6, page 71)

The practice of saving manure to spread as fertilizer seems to have declined in recent years, because the manual labor involved makes it uneconomical in comparison with machine application of commercial fertilizer.

There is a trend toward providing lagoons or other treatment of animal wastes from feedlots and similar concentrations of livestock population. Until the practice becomes more widespread, animal wastes must be regarded as a potential source of significant quantities of stream nutrients.

Transport of Phosphates to Streams and Lakes

To assess the relative amounts of phosphate and other substances transported to streams by rural runoff in the Lake Michigan Watershed, GLIRBP selected eight streams draining small rural watersheds for investigation.

During 1963-64 for a period of approximately one year, a minimum of 50 samples was taken on each stream from established sampling points.

The data collected were used to determine the quantities of PO_4 that drained from rural land each year. The composite data average was dervied from a series of samplings over a period of time. By using this average, the duration of time, and the average flow during this period, the number of pounds of PO_4 discharged per year was calculated for each stream. Values of pounds per year per square mile were then calculated by dividing the above calculated values by the square miles of drainage area of each stream. Table II shows the results.

A study of concentration vs. time showed that rivers in similar soil areas had similar concentrations during the changing seasons of the year. Each of the river basin studies was compared by soil type and land use. This information was used to determine which of the rivers were similar and what type of land each river flowed through.

Lacking enough data to cover all land use in each soil area in the Lake Michigan drainage basin, it was decided to determine chemical values for each soil area and not consider land use. By using a soil map, the Lake Michigan drainage area was found to contain eight soil groups, of which four are the most common.(7) In fact, two groups, Gray-Brown Podzolic, and Podzol-and-Brown Podzolic, cover 77 percent of the total drainage area,

TABLE II

LAKE MICHIGAN BASIN, RURAL RUNOFF QUALITY
1963-64

State-County and stream	Drainage Area sq. mi.	Range of Sampling Period	Number of Samples	Number of Analysis [1]	PO_4 Concentration Mean mg/l	PO_4 Concentration Range mg/l	Flow c.f.s. [2] Max.	Flow c.f.s. [2] Min.	Flow c.f.s. [2] Mean	PO_4 lbs. per sq. mi.
Mich-, Calhoun, Eaton Co.										
1. Battle Creek	241.0	3/27/63-4/14/64	53	22	0.30	0.05-0.62	190.0	35.0	112.5	210
Mich-St. Joseph Co.										
2. Fawn Creek	191.0	3/27/63-4/14/64	53	27	0.36	0.11-0.49	150.0	50.0	100.0	280
Mich- Barry Co.										
3. Quaker Creek	7.6	3/27/63-4/14/64	53	20	0.03	0.01-0.07	7.0	2.0	4.5	25
Mich-Mason Co.										
4. Big Sable R.	127.0	3/27/63-4/14/64	53	18	0.03	0.01-0.04	315.0	100.0	207.5	62
Mich-Manistee & Lake Co.										
5. Little Manistee R.	200.0	3/27/63-4/14/64	53	23	0.02	0.01-0.06	202.5	132.5	167.5	32
Mich-Muskegon & Oceana Co.										
6. White River	380.0	3/27/63-4/14/64	53	27	0.03	0.01-0.09	562.0	275.0	418.5	55
Mich-Mackinac Co.										
7. Black River	28.0	6/12/63-1/28/64	30	14	0.12	0.01-0.24	10.0	5.0	7.5	55
Wis.-Macitowoc & Brown Co.										
8. Branch River	65.9	4/10/63-5/5/64	41	19	0.18	0.04-0.57	20.7	3.0	11.8	31

1/ All samples were composited on a quarterly basis, proportional to flow.

2/ Some of the flows were obtained from published data, others were measured by GLIRB.

TABLE III

LAKE MICHIGAN BASIN
Rural Runoff Quality by Soil Groups, 1963-64

(All Values are expressed in lbs/yr./sq. mi.)

Index Rivers	Soil Group	PO_4
1 & 2	Gray-Brown Podzolic	250
5 & 6	Gray-Wooded	43
5	Podzol and Brown Podzolic	32
7	Organic	55
7	Humic-Gley and Low Humic-Gley	55
8	Gray-Brown Podzolic and Humic Gley	31
7	Brunizem and Humic Gley	55
7 & 8	Gray-Brown Podzolic and Lithsol	43

Land use in Watersheds 1, 2, 3 and 6 is predominately agriculture, in 4 and 5 forestry, 7 forestry and swamps, 8 agriculture and parks.

TABLE IV

LAKE MICHIGAN BASIN
Average Phosphate Reduction Over Activated Sludge

Location	Type of Process	Average % Reduction *
Peoria	Krause	30.32
Springfield	"	28.70
Gary	Conventional	55.36
South Bend	"	39.90
Ft. Wayne	"	31.55
ALL PLANTS		37.17

* Includes Soluble and Insoluble Phosphates

Note: % Reduction is based on Primary influent or (Raw Sewage) to Secondary effluent.

representing 32 to 45 percent of the total. By using the calculated PO_4 values in runoff from the different streams in several combinations in consideration of the type of soil and the stream flows, values for runoff in each of the soil groups were calculated. This information is shown in Table III. It was found that very good data were available for the two soil groups that made up 77 percent of the area. Some of the other groups were estimated by using streams that flowed mainly in that group or streams that flowed in another soil of similar type.

When phosphate information from the land runoff sampling subbasins was expanded to cover each study area, and summarized for the entire Lake Michigan Basin, results showed a total discharge of approximately 4,900,000 pounds of PO_4 annually.

Municipal Phosphate

Domestic sewage is relatively rich in phosphate compounds, containing 0.01 to 0.025 pounds per capita per day. (7) Most of this phosphate comes from human excreta and synthetic detergents. The amount of phosphate released by human metabolic breakdown is a function of protein intake and for the average person in the United States, this release is considered to be about .0075 pounds per day. Synthetic detergent formulations contain large amounts of phosphates. It is estimated that 3.5 pounds per capita, per year of phosphate are discharged as sewage from synthetic detergents.

When the above per capita figures for phosphate from human excreta and detergents are expanded to cover the entire sewered population of the Lake Michigan Watershed the quantity becomes quite large. The GLIRBP

municipal waste inventory shows that 3,731,000 people are served by sewers in this watershed.

A study of five sewage treatment plants in Illinois and Indiana found that the average phosphate removal was 37 percent. This information is shown in Table IV. Using the above figures on population and percent of treatment, along with the per capita phosphate figures, it is estimated that a total of approximately 19.5 million pounds of phosphate were discharged to the watershed each year. Of this amount, 4.9 million pounds were from land runoff while 14.6 million pounds was from outfalls.

Tributary Mouth Sampling

In addition to the land runoff sampling from the eight small subbasins, sampling stations were established at the mouths of major tributaries to Lake Michigan. These stations were also sampled continuously for one year during the same period in which the land runoff stations were sampled.

Sampling at the mouths of the tributaries made it possible to measure rather closely the total phosphate load reaching Lake Michigan from a study area. When the discharge from the rivers was determined, a summary showed a total of approximately 9,700,000 pounds of PO_4 being contributed annually to the Lake.

There are also 1,433,000 people served by sewers which outlet directly to the Lake. This results in an additional 5.0 million pounds of PO_4 entering the Lake annually.

Summary

Land runoff contributes approximately 4.9×10^6 pounds of phosphate to the tributaries. Waste sources contribute another 14.6×10^6 pounds of phosphate to the tributaries.

Based on sampling of major Lake Michigan tributaries at their mouths, approximately 9.7×10^6 pounds of phosphate are contributed to the Lake itself. Another 5×10^6 pounds are discharged directly to the Lake. The total annual phosphate input into the Lake proper is 14.7×10^6 pounds.

It may be assumed that the phosphate contributed by land runoff is proportionately distributed, i.e., 2.4×10^6 pounds trapped in the streams sediments and 2.5×10^5 pounds net input into the Lake.

Of the 24.5×10^6 pounds of phosphate input to the Lake Michigan Basin, 14.7×10^6 pounds of phosphate is deposited into the Lake proper, and 9.8×10^6 pounds of phosphate are trapped in stream's bottom sediments, shoals, and biological uptake.

Note: All phosphorus is expressed as phosphate.

REFERENCES

1. Bennett, H. H. 1939 Soil Conservation. 1st Edition, McGraw-Hill Book Company, New York, pp. 9-10.

2. Waggaman, W. H. 1952 Phosphoric, Phosphate, and Phosphatic Fertilizers, 2nd Edition, Reinhold Publishing Corp., New York, pp. 20-24.

3. Sawyer, C. N. 1944. Fertilization of Lakes by Agricultural and Urban Drainage. New England Water Works Association Journal, 61: 109-127.

4. Engelbrecht, R. S. and Morgan, J. J. Studies on the Occurrence and Degradation of Condensed Phosphate in Surface Water. Sewage and Industrial Wastes, 31: 458 (1959).

5. Walton, Graham - April 1966. Document, Agricultural Waste-Water-Treatment and Recycling for Agricultural Use, U. S. Dept. of Health, Education and Welfare, Federal Water Pollution Control Administration, Robert A. Taft Sanitary Engr. Center, Cincinnati, Ohio.

6. Nitrogen and Phosphorus in Water, An Annotated Selected Bibliography of Their Biological Effects, by Kenneth M. Mackenthun (Public Health Service Publication No. 1305).

7. Bulletin 544 - June 1960. North Central Regional Publication No. 76, Soils of the North Central Region of the United States, Agricultural Experiment Station, University of Wisconsin, Madison.

8. C. N. Sawyer, American Water Works Association Journal. Vol. 57, No. 11, pages 1431-1439.